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Elevated levels of sodium in community drinking water

Edward J. Calabrese, Robert W. Tuthill, Janelle M. Klar, and Thomas L. Sieger

A comparison study of students from towns with differing levels of sodium in drinking water revealed statistically significantly higher blood pressure distributions among the students from the town with high sodium levels. Differences were found in both systolic and diastolic readings, in boys as well as girls.

Attempts to derive a sodium standard as a result of the national Safe Drinking Water Act have been hampered by a dearth of definitive human population studies demonstrating the effects on health of sodium in drinking water. For this reason, the Environmental Protection Agency (EPA) did not propose a maximum concentration limit for sodium in drinking water.[1] The American Heart Association has proposed that a limit of 20 mg/L Na be adopted as a standard in order to afford protection to those with heart or kidney ailments who require a low sodium diet.[2]

The chronic excessive consumption of salt has long been recognized as a risk factor in the development of hypertension in animal models (e.g., rat, chicken, rabbit, dog, and monkey).[3-8] Numerous observations of humans from the early 1900s to the present in both epidemiologic and clinical studies have lent support to the hypothesis that elevated sodium exposure is a causative factor in the development of hypertension.[9-15]

Sodium intake is usually substantially greater from food than from water. Water contributes 0.5 to 9.0 percent of the total sodium consumed, with the important exception of persons on a restricted salt diet.[2,16] Generally, an "average" individual consuming 2 L of water per day at 100 mg/L Na and a daily dietary Na intake of 5.0 g would derive approximately 4 percent of his total sodium consumption from drinking water.

Nearly all previous studies of the relationship between hypertension and sodi-

TABLE 1
*Socioeconomic comparisons of the high and low sodium communities**

Characteristics	High Sodium Community	Low Sodium Community
1970 population	low 20 000s	low 20 000s
Population change (1960-1970)—percent	17.0	16.3
Median family income—$	13 434	12 281
Median schooling—years	12.7	12.5
Black population—percent	0.4	0.7
Foreign-born population—percent	6.0	5.7
Water sodium level (1978)—mg/L	107	8

*1970 US Census data

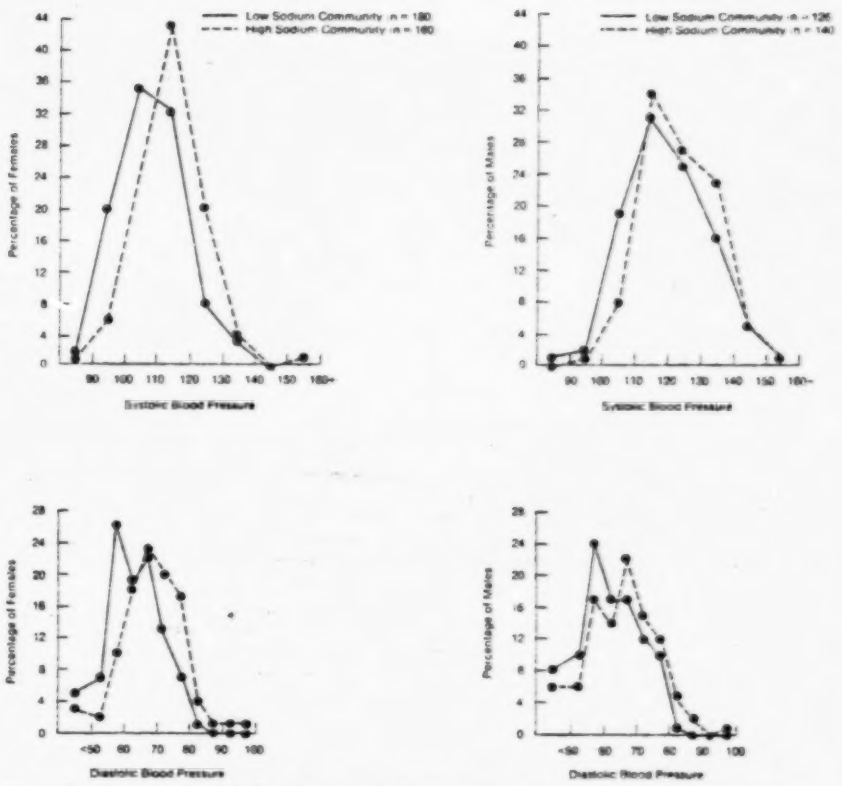
Low Sodium Community (n = 180)
High Sodium Community (n = 180)
Low Sodium Community (n = 126)
High Sodium Community (n = 140)
Percentage of Females
Percentage of Males
Systolic Blood Pressure
Diastolic Blood Pressure

Fig. 1. Systolic and diastolic blood pressure distributions by sex for tenth grade students f high (107 mg/L) and low (8 mg/L) sodium communities

um intake have considered the contribution of sodium from food rather than water. However, several studies have indicated that elevated levels of sodium in drinking water adversely affect patients with Meniere's disease[17] and heart disease.[18] Sodium in the drinking water was also associated with the increased cardiovascular death rates observed in the population of Dallas when, during the 1950s drought, water with high sodium levels was imported.[19]

The present paper summarizes two years' research designed to assess whether elevated levels of sodium in community drinking water could bring about an increase in the blood pressure (BP) levels of elementary (third grade) and high school (tenth grade) students.

Tenth grade study

The authors compared BP distributions among students in two geographically contiguous Massachusetts communities markedly similar with regard to size, income, education, and recent rate of growth. One community had low levels of sodium in its drinking water, while the other had much higher levels (8 mg/L and 107 mg/L, respectively). These differences in sodium levels have existed for seventeen years (Table 1).

Methods. The tenth grade class of the public high schools in the two communities was chosen as the population to be surveyed. Of approximately 850 tenth grade students in the two schools, 606 had permission to be screened, for an overall response rate of 70 percent. Three hundred students in the high sodium community and 306 in the low sodium community participated.

The screenings were scheduled so that 150 students were screened on each of four days, two successive days in one community and the same two weekdays of the following week in the second community. Thus the screenings were conducted at the same times in mornings and afternoons in each town.

Four highly skilled and carefully trained nurses took the BP of the students, with three working at a time on a 45-min rotation. The same nurses took the BP readings at both schools on all four days. The aneroid manometers used were standardized twice each day in order to minimize the effects of recent food intake and exercise on BP. The students were screened at least 45 min after a meal and did not attend classes at least 1 hr before being screened. The students were brought quietly to the screening area and spent at least 6 min seated, completing a questionnaire, before proceeding to the stations where they progressed to each of the nurses for a casual, seated BP reading on the left arm. Each nurse was blind to the previous reading for each person. Thus three readings were obtained for each student, and these measurements were averaged to provide an estimate of the BP for each individual. The pulse rate for each was recorded by the nurse at the first station, although it was taken by each nurse.

The questionnaire completed by each student was designed to provide information with regard to variables known to affect BP. If any of these factors differed significantly between the two communities, they could then be controlled in the analysis. Information was

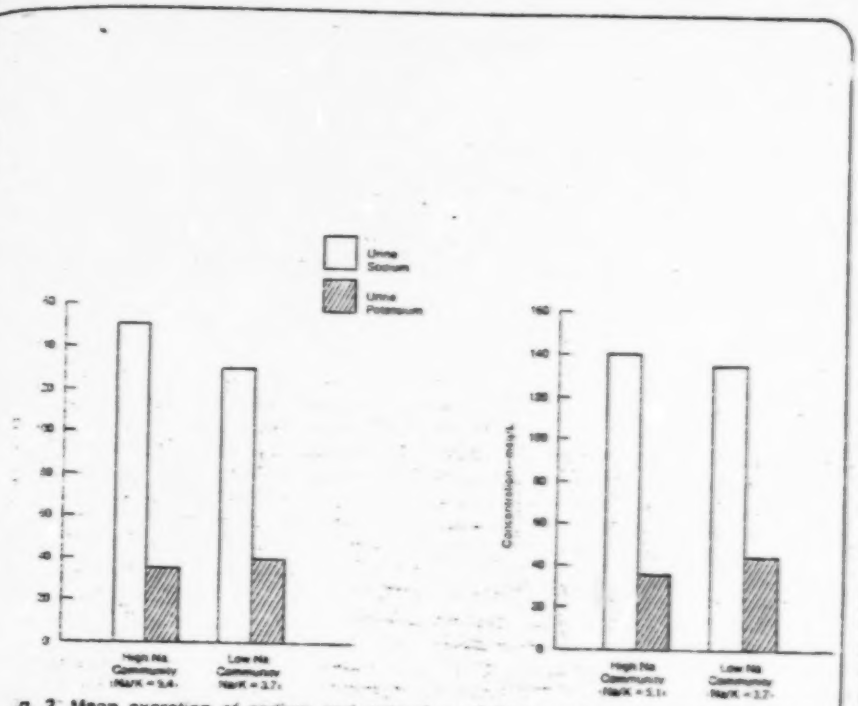
Urine Sodium
Urine Potassium
Concentration—mEq/L
High Na Community Na/K = 5.4
Low Na Community Na/K = 2.7
High Na Community Na/K = 5.1
Low Na Community Na/K = 2.7

Fig. 2. Mean excretion of sodium and potassium of first morning urine samples and the corresponding sodium/potassium ratio (Na/K) for third grade boys and girls from high and low sodium communities.

obtained on age, height, weight, length of residence in town, smoking history, length of time since last cigarette and last meal, recent excessive weight gain or loss, whether on a low sodium diet, eating habits in relation to salty items, amount of community water drunk either plain or mixed in a drink such as orange juice, health status, occupation and education of the family's principal wage earner, and whether subjects were currently taking any BP medication.

Results. The students of the high sodium community showed the hypothesized upshift along their entire BP distribution when compared to the low sodium community students. Figure 1 illustrates this upshifted distribution, which occurred for both systolic and diastolic BP and was consistent for both sexes, although more pronounced for females.[9] The mean systolic and diastolic BP for females in the high sodium community was 113.5/67.8 mm Hg compared to 108.4/62.7 mm Hg in the low sodium community. The difference between the two groups of females for both systolic and diastolic BP was 5.1 mm Hg, a difference statistically significant at the $p < 0.001$ level. The same upshift in the population distribution for BP occurred with the high sodium males as with the females, but not to the same degree. Among males the mean systolic and diastolic BP in the two communities was 123.1/65.2 mm Hg in the high sodium community and 119.5/62.5 mm Hg in the low sodium community. The differences in mean systolic and diastolic BP between the two male groups were 3.6 mm Hg and 2.7 mm Hg, respectively. Both these differences were statistically significant at $p < 0.01$.

Statistical analyses designed to evaluate the possibility of confounding revealed no statistically significant variables between the tenth grade groups from the two communities that were also statistically significant in relation to BP within the population.

Other statistical analyses were designed to adjust mean BP simultaneously for any differences between the communities' student groups with regard to eighteen variables on the pupil questionnaire. Although minor changes in the mean values occurred as a result of these statistical analyses, the fundamental findings of the study were supported.

Third grade replication study

A third grade study in the same two communities was carried out to confirm the earlier findings by possibly replicating the tenth grade differences and to rule out such potentially confounding variables in the first study as possible differential illicit drug use in the two high school populations.

Methods. Seven elementary schools were located in each community with 384 third graders in the high sodium community and 301 third graders in the low sodium community. In the high sodium community 346 out of 384 children were screened, and in the low sodium community 262 out of 301 children were screened for net participation rates of 90.1 and 87.0 percent, respectively.

The screenings were conducted in fourteen sessions over eight school days within a two-week period. Careful attention was paid to ensure that the towns were screened equally on mornings and afternoons in order to eliminate diurnal variation in BP as a possible confounding variable. In each town four schools were screened in the morning and three in the afternoon. This resulted in 65.2 percent of the high sodium community children being screened in the morning, compared to 69.7 percent in the low sodium community.

Five nurses who had been carefully trained were available to do the screening. The same four nurses did the screening at eleven of the sessions, with the fifth nurse substituting for one of the other four during three of the sessions. Three children at a time were screened at three different stations, each child moving from station to station, so that three casual BP readings on the left arm using a mercury sphygmomanometer at eye level were recorded for each child. Each reading was taken by a different nurse who was blind to the readings of her colleagues. The nurses rotated through the stations on a time schedule, with only three of the four working at a time, one at each station. Pulse rate was recorded by the nurse working at the first station using procedures similar to those previously described.

The children were brought to the screening area (usually a gym, auditorium, extra room, or school nurse's office) slowly and quietly, and were seated quietly for several minutes before being screened. No gym classes were scheduled in the hour prior to the screening, and meals were consumed at least 45 min before the screening. Age, height, and weight had been measured in the immediately preceding months by the school nurses. The school scales were checked for accuracy at the time of

screening, and all weighed to within 1 lb of a 40-lb weight (which approximated the weight of these children).

Additional information on factors related to BP was obtained for each child from a short questionnaire completed by the parents in conjunction with the permission slip. The questionnaire provided information on family history of high BP, source of drinking water, length of residence in the town, medications being taken by the child that might affect BP, infant feeding habits, and the education level and occupation of the principal wage earner in the family. As in the tenth grade study, the three BP readings for each child were combined to form an average reading on which subsequent analyses were based.

Results. The initial results for the third graders supported the original high school findings. A statistically significant difference existed in mean BP between the two communities for both boys and girls for systolic and diastolic BP. The mean systolic and diastolic BPs for boys from the high and low sodium communities were 101.3/56.3 and 98.0/53.7 mm Hg, respectively. This represented a difference in systolic BP of 3.3 mm Hg ($p < 0.001$); a 2.6 mm Hg difference in mean diastolic BP was apparent for the girls. The high sodium community girls' mean BP was 97.9/58.1 mm Hg, compared with 95.3/54.4 mm Hg among the low sodium community girls. The resulting systolic and diastolic BP differences were 2.6 and 3.7 mm Hg, which were statistically significant at $p = 0.023$ and $p = 0.002$, respectively.

As with the tenth graders, upshifts for the third grade boys and girls occurred along the entire distribution of systolic and diastolic BP. The upshift was least marked for systolic BP for girls and most distinct for systolic BP for boys. However, the pattern was completely consistent for all four comparisons. When testing the statistical significance of the difference in the two distributions for each of the four comparisons using the Kolmogorov-Smirnov two-sample test, the female systolic distributions did not differ statistically between the two towns at $p = 0.14$. The female diastolic comparison and the male systolic and diastolic comparisons revealed statistically significant differences by community of at least $p = 0.008$.

These results are very similar in pattern to the differences found in the screening of the tenth grade populations of these two communities. Clearly, the consistent pattern of the results for both sexes for both systolic and diastolic BP readings among the third graders, and their consistency with the earlier tenth grade findings, lends importance to these results in conjunction with their statistical significance.

The statistical assessment of these data, which will be presented in a subsequent article, upheld the initial findings. In fact, the statistical adjustment for differences in the confounding characteristics resulted in an adjusted difference in mean BP between the two towns that was even greater than when these factors were uncontrolled; the net impact of adjusting for differences in height, weight, and socioeconomic status was a larger difference in systolic and diastolic BP between the towns for both sexes.

The resultant adjusted differences were all statistically significant. The difference in diastolic BP between high and low sodium community boys had an associated significance level of $p = 0.014$. For the difference in systolic BP between both high and low sodium community boys and girls and for the difference in diastolic BP between high and low sodium community girls, the associated significance level was $p \leq 0.001$.

In addition to statistical significance, the clinical implications of the difference in BP at this age may be of some significance for the future BP levels of the children from the high sodium community. The average increments of increase in systolic and diastolic BP from ages seven to eleven, using NCHS[21] statistics, are 1.5 and 0.9 mm Hg per year, respectively. Thus a difference of 3 to 4 mm Hg between the high and low sodium community children can be extrapolated to indicate that the high sodium community children are approximately two to two-and-a-half years older in systolic BP development and three to four years older in diastolic BP development than their low sodium community counterparts. Should these differences continue into adulthood, hypertensive BP levels could be reached years earlier among persons at the high end of the distribution in the high sodium community.

Third grade followup study

In addition to evaluating BP levels, a 24-hr diet record, a first-morning urine sample, and a household water sample were obtained from the participants. In the diet record food intake was recorded after each meal. While the dietary information and drinking water samples are in the process of being analyzed, analysis of the urine for sodium and potassium revealed that both males and females from the high sodium community displayed higher excretory values for sodium and lower values for potassium than the low sodium community, as illustrated in Fig. 2. This resulted in a considerably higher Na-K ratio among the high sodium community children, the ratio being 5.4 for boys and 5.1 for girls. In comparison, the Na-K for both sexes in the low sodium community was 3.7.

These data are of significance because they provide the first direct linkage of greater sodium exposure in the groups of students with elevated BP.

Bottled water study

In an effort to further evaluate the hypothesis that the increased BP in the high sodium community students is caused by the sodium in the drinking water or other drinking water factors, a bottled water study has been initiated. The third grade students from the high sodium community participating in this phase of the research have been divided into three groups. Group 1 is given water from the low sodium community (8 mg/L Na), group 2 is given water from their own community's distribution system (107 mg/L Na), and group 3 receives water from the low sodium community to which sodium chloride has been added to a sodium level equivalent to that in the high sodium community water. Water is provided to both the homes and schools of the participating children in bottles having color-coded caps and is to be utilized for all drinking and cooking needs. The participants do not know which type of water they are drinking. BP of the children is monitored every two weeks, and overnight urine samples and 48-hr diet records are obtained each month.

This study is designed to be conducted over a twelve-week period. The strengths of the study design are that (1) it provides a complementary approach to answering the original study hypothesis as compared to the original two studies; (2) comparison students can be much more closely matched—by BP, sex, school, and section of the community; (3) more complete information on dietary intake can be obtained; and (4) the experimental nature of the study permits more accurate assessment of the possible contribution of drinking water factors other than sodium and chloride. The negative feature is that the twelve-week duration of the study may not be long enough to uncover changes in BP.

Conclusion

Epidemiologic investigations in Massachusetts have revealed that the BP of third and tenth grade students from a community with 107 mg/L Na drinking water was significantly upshifted as compared to similarly aged students from a closely matched, geographically contiguous control community with only 8 mg/L Na. In light of the multifactorial origin of differential blood pressure levels between individuals and groups, these findings must be interpreted with caution, although careful statistical analysis has effectively eliminated many of the potentially confounding variables. It is hoped that ongoing studies that more effectively address the relationships of dietary sodium consumption and exposure to sodium via drinking water will

provide more definitive conclusions.

Acknowledgment

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